UDC 621.774.32

Perfection of Procedure for Calculation of Force Parameters for Cross Roll Piercing of Billets

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Abstract
The article gives grounds for potential application of elongating mill as rotary piercing mill. Advanced procedure for calculation of pressure and rolling torque for rotary piercers has been elaborated.
Key words: ELONGATING MILL, SHELL, PIPE, ROLLING TORQUE.

At PJSC INTERPIPE NTRP, persistent efforts are taken to enhance the product range and to improve quality of pipes produced for oil industry. Oil pipes make sizable group (both for importance and for production volume). Considering the total production output, modules with Pilger mills play leading role in production processes at the plant. Toughening of requirements to pipe quality have demanded for transition to more sophisticated steelmaking and rolling methods, which is possible only on condition of large-scale renovation of steelmaking and rolling-mill processes. Investigations conducted for advancement of steel melting and casting, billet piercing and shell rolling have served as the scientific background for techno-economic justification of the work package. Investigations in the sphere of advanced production of seamless pipes have covered procedures from metal preparation for rolling to pipe finishing. Assessment of the potential expansion of the pipe production range has been the key aspect.

For production of hot-rolled pipes with diameters of 168 mm to 377 mm and above at pipe rolling modules with Pilger mills, rotary piercing mill is, as a rule, used as piercing facility. In case of Pipe Rolling Mill-4, PJSC INTERPIPE NTRP, elongating mill available in the process chain serves the purpose. Recommendations for sizing of mill work rolls and piercing plugs have been worked out on the basis of analysis of deformation zone geometry, force parameters of direct piercing.

Under this work, calculations have been carried out for checking reliability of individual equipment components for rolling of pipes of both present product range and new sizes (Ø168-426 mm).

In this context, procedure for calculation of pressure and rolling torques for rotary piercers [1,2] has been refined. Rolling torque can be treated as derivative of frictional forces arising during contact of metal with roll [3]. According to recommendations [4], such method can be used during continuous slipping of metal in deformation zone; and cross piercing processes are characterized with well-developed slipping of metal in axial and tangential directions with regard to rolls. Under production conditions, tangential forward slipping at deformation zone inlet and outlet sections is practically not available in work roll passes.

The essence of the procedure lies in division of deformation zone along length into the following sections: I – plugless rolling (before contact of metal with plug); II – rolling on stationary rotating plug; III – plugless shell (pipe) reeling in outlet cone of deformation zone (fig. *1*). Total rolling torque *M* and rolling pressure *P* are specified as sum of the same at elementary areas *Mi* and *Pi,* equal to half feed step during one billet revolution *Si* with deformation zone being filled with metal at two-high mill (equal to one-third feed step for three-high mill):

$$M = \sum_{i-1}^{n} M_i \,;\; P = \sum_{i-1}^{n} P_i \,;\; M_i = P_i \cdot R_{Bi} \cdot f_i \,; \quad (1)$$

where *RBi*– roll mean radius, equal to half-sum of radii at the ends of the elementary area; *fi* – friction coefficient.

Under steady-state rolling conditions, friction coefficient is calculated in line with recommendations [5]:

$$f_i = R_h \cdot (0{,}55 - 0{,}00024 \cdot t) \quad (2)$$

where *t*- rolling temperature.

Radius *Rh* for cast iron rolls is 1 mm, for steel rolls – 1.2 mm, for steel ragged rolls – 1.5 mm. Values of radius *Rv* are as follows:

Velocity of roll periphery, m/s	0 – 1.0	2.0	2.5	3.0	4.0	5.0
Rv	1.0	0.9	0.75	0.65	0.55	0.5

Rolling pressure at elementary area is:

$$P_i = 0{,}5 \cdot p_i \cdot S_i \cdot l_i \quad (3)$$

where *pi*– mean specific roll pressure at elementary contact area *li* wide.

Mean specific roll pressure is estimated from formula:

$$p_i = n_\sigma \cdot n_\beta \cdot n_3 \cdot n_v \cdot n_\varepsilon \cdot n_{СД} \cdot \sigma_S,$$

where *nσ* – coefficient of backup considering effect of friction in the direction of roll rotation; *nβ* – coefficient considering effect of friction in direction transverse to roll rotation direction (*nβ* = 1.155); *n3* – external area influence coefficient; *nv*– coefficient considering effect of velocity of roll periphery.

Herewith, coefficient *nv* varies within the following limits:

v,m/s	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
nv	1.35	1.70	1.75	1.85	1.40	1.91	1.92	1.93	1.94	1.95

nε – coefficient considering effect of reduction rate along billet (pipe) diameter or wall thickness *εCP*:

Δ, %	1	2	3	4	5	6	7	8	9	10
nε	1.19	1.35	1.45	1.55	1.62	1.67	1.69	1.71	1.73	1.75

nСД – coefficient considering effect of wall bending at plugless rolling sections (for solid body and in case of plug rolling - *nСД*=1;

σS – plastic limit during static testing[6].

Coefficient of backup [2]:

$$n_\sigma = \left[\frac{h_{i_{cp}}}{(f_i \cdot e)}\right] \cdot \left[a \cdot (1 + f_i a) + \exp(-\ln 2 \cdot f_i)\right] \quad (4)$$

$$a = 0{,}5 \cdot \left[\frac{l_i}{h_{i_{cp}}} + \frac{(\ln 2 \cdot f_i)}{f_i}\right] \quad (5)$$

Coefficient of external zones influence is as following [7]:

$$n_3 = 2\exp\left(\frac{-0{,}7 \cdot l_{i_{cp}}}{h_{i_{cp}}}\right) \quad (6)$$

where *hiCP*– diameter of billet (hollow feed) in deformation zone *DiCP* or wall thickness and C*iCP* (mean) for elementary contact area.

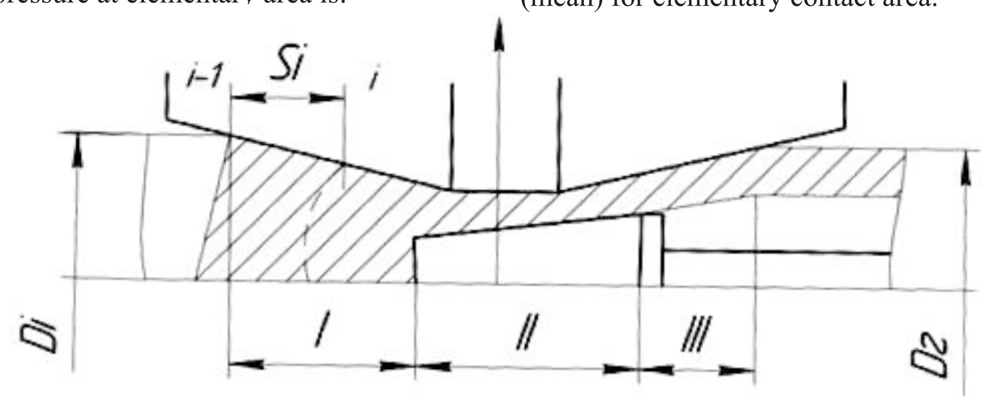


Fig. 1. Deformation zone of piercing mill (elongating mill)

Value of coefficient *nСД* is specified by the formula:

$$n_{СД} = \left(\frac{2 \cdot C_{i_{СР}}}{D_{i_{СР}}}\right) \cdot \left[\left(\frac{C_{i_{СР}}}{D_{i_{СР}}}\right)^{-1} - 1\right]^{-1} \quad (7)$$

The length of elementary surface of metal contact with roll for barrel-type rolling mills:

$$S_i = 0{,}5 \cdot \pi \cdot D_Г \cdot \left(\frac{F_Г}{F_{i-1}}\right) \cdot \left(\frac{\eta_0}{\eta_T}\right) \cdot tg\alpha \quad (8)$$

where *DГ* – diameter of shell; *FГ* – cross section of shell; *Fi-1* – cross section of feed in the beginning of elementary contact area; *ηo* – coefficient of tangential metal slip against rolls in the outlet section of the deformation zone; *ηт* – coefficient of tangential slip in the same place; *α* – rolls feed angle (effect of rolls toe angle *β* can be neglected in this case).

Average value of *liCP*, *hiCP,* and *εCP* shall be specified from the formulas:

$$l_{i_{СР}} = 0{,}5 \cdot (l_{i-1} + l_i) \quad (9)$$

$$h_{i_{СР}} = 0{,}5 \cdot (D_{i-1} + D_i) \quad (10)$$

Formula (10) is referred to the I and III areas of deformation zone (pic. 1):

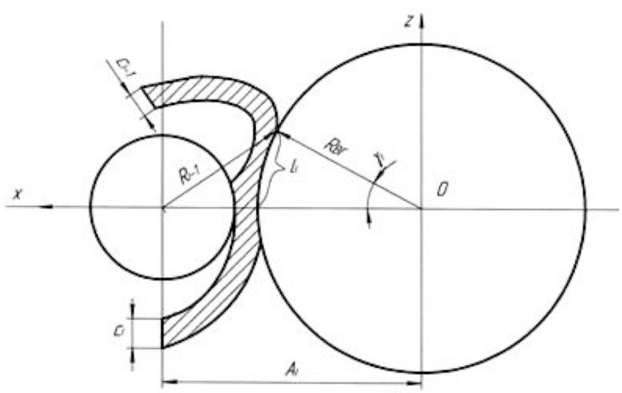
$$h_{i_{СР}} = 0{,}5(C_{i-1} + C_i) \quad (11)$$

Formula (11) is referred to the II area:

$$\varepsilon_{CP} = \left[\frac{1-(D_{i-1} - D_i)}{D_{i-1}}\right] \cdot 100 \quad (12)$$

Formula (12) is referred to the I and III areas:

$$\varepsilon_{CP} = \left[\frac{1-(C_{i-1} - C_i)}{C_{i-1}}\right] \cdot 100 \quad (13)$$



Pic. 2. Diagram of metal contact with the roll

Formula (13) is referred to the II area. The width of the contact surface in the section of the deformation zone is specified by the following formula (pic. 2):

$$l_i = R_{ВГ} \cdot \gamma_i , \quad (14)$$

where *RВГ* – radius of the roll in the section of zone *II*; *γi.* – central angle of arc of metal contact with the roll (roll cross angles are neglected to simplify the calculation):

$$\gamma_i = \frac{\left(R_{ВГ}^2 - R_{i-1}^2 + A^2\right)}{\left(2 \cdot A \cdot R_{ВГ}\right)}; \quad (15)$$

$$R_i = R_{i-1} \cdot \lambda_{i-1} \quad (16)$$

where *Ri-1* – radius of the feed in the section of deformation zone *i-1*; *Ai* – distance from projection of ℄roll onto horizontal plane upto axes of rolling in section *i*.

The values of the parameters included to the formulas (14) and (16) are determined for particular mill in accordance with generally accepted relations considering specification of parameters of deformation zone as per piercing process model described in the work [6].

Results of checking calculation developed for process of direct piercing on elongating mill ТПА 5-12'' from billets of 385 - 500 mm diameter to large-sized shells required for rolling of pipes made of steel *Д* of 8-13 inches size at constant feed angle of 4 and 6° are provided in the table 1.

It was determined from the calculation that the values of pressure on roll will be maximum at piercing of billets of diameter more than 370 mm (see table 1).

From the analysis of the data given in Table 1, it can be concluded that it is necessary to provide modernization of existing elongating mill for direct piercing of billets of diameter more than 370 mm.

The primary action focused on modernization of elongating mill may be change of rolls sizing (increase of feed angle) with strengthening of main drive.

Due to calculations, it was possible to establish that some reserve for ТПЦ-4 elongating mill of PJSC ITERPIPE NTZ has some reserve for expansion of diameter of original billets upto 500 mm (for pipes of 426 mm diameter).

Developed improved method of calculation of power parameters for skew rolling mills can be used during designing of new mills and development of checking calculations for skew rolling mills of different purposes.

Table 1. Power and linkage parameters at direct piercing of billet continuous casting at elongating mill

Sl.No .	Size of rolling pipe, mm	Diameter of ingot	mold tube diameter		Feed angle				Temperature	Grade of steel	Pressure on one roll, P (inlet+outlet)		Axial pressure on one roll, t	Axial pressure on	Capacity W, kW	Rolls diameter, mm	Speed of mill
1	15	2	3	4	5	6	7	8	9	10	11	12	13		14	16	17
1	219 (8)	385	360	63,0	4	1,1	7	10	1150	Д	326 (182 + 144)	49	55	114	2762	750	0,133
2	245 (9)	385	360	60,0							327 (182 + 145)	49	55	114	2765	750	0,133
3	273 (10)	450	420	73,0							393 (219 + 174)	65	66	138	3676	750	0,133
4	299 (11)	450	435	68,0							403 (224 + 179)	70	68	141	3933	750	0,130
5	325 (12)	450	445	60,0							410 (228 + 182)	73	69	144	4096	750	0,128
6	426. мм	495	540	63,0							512 (290 + 222)	124	86	179	6971	875	0,141
7	219 (8)	385	360	63,0	6						395 (220 + 175)	73	67	138	4121	750	0,200
8	245 (9)	385	360	60,0							395 (220 + 175)	73	67	138	4131	750	0,200
9	273 (10)	450	420	73,0							476 (265 + 211)	98	81	167	5504	750	0,199
10	299 (11)	450	435	68,0							491 (273 + 218)	105	83	172	5925	750	0,195
11	325 (12)	450	445	60,0							498 (277 + 221)	109	84	174	6140	750	0,192
12	426 (13)	495	540	63,0							637 (361 + 276)	190	108	223	10710	875	0,211

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